Detection of Crack Using Genetic Algorithm
Mitesh J. Mungla, Dharmendra S. Sharma and Reena R. Trivedi

Abstract—Genetic algorithm based intelligent search of crack parameters (location and its severity) in cantilever beam has been presented in the paper. Algorithm is prepared to find global minima of fitness function which is function of measured and theoretical natural frequencies. Theoretical model of cracked beam has been derived based on Euler-Bernoulli beam theory. The crack, open and uniform depth, is modeled as rotational spring connecting two segments of an integrated beam. For validation of proposed method, the cracks are generated at various locations on specimens (made of aluminum alloys (6061-T6) using wire cut electro discharge machining process (WEDM). The results are found to be in good agreement with the actual crack parameters.

Keywords—Crack Detection, Euler-Bernoulli Beam, Non-Destructive Technique (NDT), Genetic Algorithm (GA), Rotational Spring

I. INTRODUCTION
LAST few decades, many non-conventional non-destructive techniques (NDTs) have been developed for detection of crack location. Especially, vibration based NDTs have opened new research dimension and become one of the potential alternative for identification of crack because of ability to overcome many limitations of conventional NDT

Local crack presence in the component globally affects modal parameters of it. Based on that reference, many researchers attempted to develop mechanism for detection of single/multiple cracks in last two and half decades. Adams et al. [1] and [2] simulated crack as rotational spring and established base for detection of crack for longitudinal vibration of bar. Many researchers explored the field for different components with vivid combinations and try to generalize methodology and applicability to most of all mechanical and civil engineering components, not only for crack detection but also for health monitoring and fault diagnostic purposes. Dimarogonas [3] has widely reviewed literatures related to crack modeling and crack detection strategies in various mechanical/structural components like bar, beam, turbine blades, shaft etc.

Similarly, in the last decade or so, many researchers have employed stochastic methods like artificial neural networks (ANN), genetic algorithms (GAs), particle swarm optimization (PSO) etc. for identification of crack parameters. Combination of vibration (natural frequency) based data as input for artificial neural networks (ANNs) to predict crack location and severity in beam like structure and laminates have been presented by Sahin and Shenoi [4], [5]. GA based crack detection was studied in beam-like structure using natural frequency based data input by Vakil-Baghmisheh et al. [7] and wavelet based elements by Xiang et al. [9]. Vakil-Baghmisheh et al. [8] prepared algorithm using PSO for crack detection in cantilever beam.

In present paper, natural frequency data of beam-like cantilever structure are coupled with genetic algorithm based search mechanism for identification of location and depth of the crack. The present work is validated through number of experiments.

II. FORMULATION OF CRACKED BEAM
The governing equation of transverse vibration of the uniform intact beam can be derived using Euler-Bernoulli beam equation as,

\[ \sigma(x) \frac{d^4 y(x)}{dx^4} + \lambda^4 y(x) = 0 \]  

where \( y(x) \) is lateral deflection of beam,

\[ \beta = \left( \frac{x}{L} \right) \]  

is normalized location, \( x \) is distance of beam measured from fixed end, \( \lambda = \left( \frac{\sigma^2 \rho A E}{E I} \right)^{1/4} \),

where \( \sigma \) is natural frequency of the beam and \( \rho, E, A, L \)

and \( \beta \) density, Young’s modulus, cross sectional area, total length and moment of inertia of the beam respectively.

The (lateral deflection) solution of uncracked beam (1) can be expressed as follows.

\[ y(x) = A_1 \cosh(\lambda x) + B_1 \sinh(\lambda x) + C_1 \cos(\lambda x) + D_1 \sin(\lambda x) \]  

The open crack existing on the beam can be modeled as rotational spring having stiffness ‘\( K_c \)’. This rotational spring separates an intact beam into two segments connected through it shown in figure 1. Thus, stiffness ‘\( K_c \)’ varies from zero (when thorough crack) to infinite (no crack).

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Equations (3) and (4) along with boundary conditions (7)-(10) and compatibility conditions (11)-(14) yields eight characteristic simultaneous equations:

\[ A_y \cdot B_y = 0 \]  

where,

\[ B_y = \begin{bmatrix} A_1 & B_1 & C_1 & D_1 & A_2 & B_2 & C_2 & D_2 \end{bmatrix} \]

For non-trivial solutions, \( |A_y| = 0 \) yield natural frequencies of cracked beam. Thus, \( f(\beta, \lambda, K) = 0 \).

III. GENETIC ALGORITHM

GA is an optimization approach which quickly searches global maxima/minima of complex problem and works based on survival of fittest principle. The flowchart of algorithm for the presented problem is shown in figure 2. In presented work, algorithm initiates with random initial selection of chromosomes (initial population). Each chromosome constituted with string of normalized crack location \( 0 \leq \zeta \leq 1 \) and crack severity \( 0 \leq \xi \leq 1 \), where \( \zeta = a/l \).

Using forward method, the theoretical natural frequencies are obtained from the model (15) for a chromosome.

Algorithm is prepared to minimize the fitness function, that is defined as;

\[ \text{Fitness function} = \sum_{i=1}^{n} \frac{\text{abs} (NT_i - NM_i)}{2} \]  

where \( NT_i \) are the first five theoretical natural frequencies and \( NM_i \) are the first five natural frequencies, measured through experiments. Zero value of fitness function indicates exact match of theoretical and measured frequencies which is almost difficult to achieve. In such condition, convergence value of fitness function needs to adopt.
IV. RESULT AND DISCUSSIONS

To validate the integrity of the presented study, test-set up, consists of a) vibration isolation platform, b) accelerometers, c) data acquisition system and d) data analysis software, is employed to carry out experiments with clamped-free condition.

Four beam (three cracked and one intact) specimens of 270 mm long aluminium alloy material (6061-T6) having cross section (40 mm width and 5 mm thickness) are prepared for the study shown in figure 3. The cracks at various locations (50 mm, 150 mm and 200 mm from free ends) of 1 mm, 2 mm and 3 mm depth on the three specimens are generated using wire cut electro discharge machining process (W-EDM).

Figure 3: Intact and Cracked Specimens of Aluminum Alloy

Measured natural frequencies of cracked aluminum beam obtained using multichannel data acquisition system; they have been presented in Table 1.

Algorithm is prepared on MATLAB software. Many runs, with combinations of different alternatives of three operators, have been executed to obtain prompt and accurate convergence. In present case, parents are selected based on highest probability (roulette wheel) from mating pool. Each pair (two chromosomes) procreates two offspring through single point crossover. To avoid local minima and infiltration of unwanted chromosomes (those matches with their parents), adaptive feasible operator randomly generates directions that are adaptive with respect to the last successful or unsuccessful generation. It is found that fitness function converges within 50 generations.

Convergence of fitness function of test point 2 is displayed in figure 4. Normalized crack locations and normalized crack severities for test point 2 and 3 have been displayed after 50 generations in figure 5 and 6 respectively. Estimated crack location and crack depth ratio of all test points are shown in Table 2.
Table 1: First Five Measured Natural Frequencies of Test Points

<table>
<thead>
<tr>
<th>Test Point No.</th>
<th>Normalised Crack</th>
<th>Measured Natural Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$S$</td>
<td>$a/t$</td>
</tr>
<tr>
<td>1</td>
<td>0.2593</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td>0.4444</td>
<td>0.2</td>
</tr>
<tr>
<td>3</td>
<td>0.8148</td>
<td>0.2</td>
</tr>
<tr>
<td>4</td>
<td>0.2593</td>
<td>0.4</td>
</tr>
<tr>
<td>5</td>
<td>0.4444</td>
<td>0.4</td>
</tr>
<tr>
<td>6</td>
<td>0.8148</td>
<td>0.6</td>
</tr>
<tr>
<td>7</td>
<td>0.2593</td>
<td>0.6</td>
</tr>
<tr>
<td>9</td>
<td>0.8148</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Table 2: Actual and Estimated Crack Parameters of Aluminum Alloys

<table>
<thead>
<tr>
<th>Test Point No.</th>
<th>Norm Crack Loc.</th>
<th>Crack Depth Ratio</th>
<th>Est. Norm Crack Loc</th>
<th>Error (%)</th>
<th>Est. Crack Depth Ratio</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.2593</td>
<td>0.20</td>
<td>0.270</td>
<td>4.13</td>
<td>0.211</td>
<td>5.50</td>
</tr>
<tr>
<td>2</td>
<td>0.4444</td>
<td>0.20</td>
<td>0.450</td>
<td>1.26</td>
<td>0.215</td>
<td>7.50</td>
</tr>
<tr>
<td>3</td>
<td>0.8148</td>
<td>0.20</td>
<td>0.771</td>
<td>-5.38</td>
<td>0.216</td>
<td>8.00</td>
</tr>
<tr>
<td>4</td>
<td>0.2593</td>
<td>0.40</td>
<td>0.261</td>
<td>0.66</td>
<td>0.408</td>
<td>2.00</td>
</tr>
<tr>
<td>5</td>
<td>0.4444</td>
<td>0.40</td>
<td>0.448</td>
<td>0.81</td>
<td>0.408</td>
<td>2.00</td>
</tr>
<tr>
<td>6</td>
<td>0.8148</td>
<td>0.40</td>
<td>0.789</td>
<td>-3.13</td>
<td>0.414</td>
<td>3.55</td>
</tr>
<tr>
<td>7</td>
<td>0.2593</td>
<td>0.60</td>
<td>0.260</td>
<td>0.27</td>
<td>0.612</td>
<td>2.00</td>
</tr>
<tr>
<td>8</td>
<td>0.4444</td>
<td>0.60</td>
<td>0.446</td>
<td>0.36</td>
<td>0.611</td>
<td>1.83</td>
</tr>
<tr>
<td>9</td>
<td>0.8148</td>
<td>0.60</td>
<td>0.791</td>
<td>-2.92</td>
<td>0.610</td>
<td>1.67</td>
</tr>
</tbody>
</table>

Figure 4: Convergence of Fitness Function of Test Point 2

Figure 5: Crack Parameters of Test Point 2 after 50 Generations

Figure 6: Crack Parameters of Test Point 3 after 50 Generations
Material properties, used in the theoretical formulation, are slight different than that of actual properties. To increase the accuracy of prediction of crack parameters, correction to material properties (‘zero settings’) of beam material need to be provided. Correction factors of material properties can be obtained by comparing measured and theoretical natural frequency of intact beam.

Formulation of clamped-free cracked beam is only applicable to isotropic and homogeneous materials with only open and single crack.

V. CONCLUSION AND FUTURE ENHANCEMENT

It has been observed that error in prediction of crack location and its severity using GA is within 5.5 % and 8 % respectively. However, increase the number of natural frequency in fitness function reduces error. But, at the same time, it increases computation time.

Following further enhancements of work can be possible.

1. Multiple crack locations can be also predicted by combination of vibration parameter and GA.
2. Formulation and identification mechanism can be extended to inclined crack in various other mechanical/structural components like shaft, pipe, rotor blades etc.
3. The formulation can be further extended for different end fixities (i. e. Free-Free, Fixed-Fixed, Fixed-Free etc.).

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REFERENCES


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